Sub-megawatt DFC/T® Test Results and Future Plans

A Powerful Opportunity

3rd Annual DOE/U.N. Hybrid Conference and Workshop

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Vision 21 DFC/T® Project Objectives

- Design of multi-MW hybrid power plants
- Natural gas systems with ultra high efficiency (up to 75% LHV)
- Ultra low emissions: <.01 lbs/MMBTU of SO_x and NO_x
- Cost competitive with other energy systems
- Demonstration of DFC/T concept in subMW power plant configuration at Danbury and in Montana

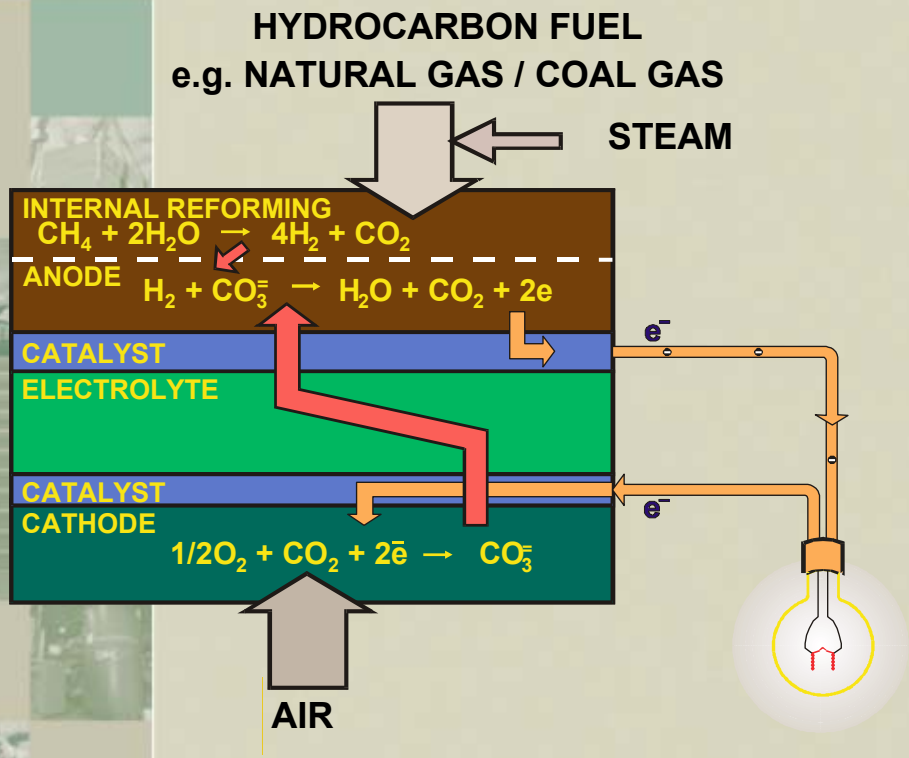
Project Status

- **SUBSCALE HYBRID POWER PLANT**
  - Proof-of-concept tests of 250 kW stack and Capstone Model 330 completed after over 6,800 hours of operation including 2900 hours in DFC/T hybrid mode.
  - NO_x emissions below the detection limit of 0.1 ppm
  - Power plant modifications including integration of a larger microturbine (Capstone C60) completed
  - Operation of the modified system is underway
  - **Multi-MW POWER PLANT DESIGN**
  - Conceptual design for 75% (LHV) efficient power plant initiated
  - Parametric studies with regard to the effects of gas turbine compression ratio on power plant efficiency initiated
- **DFC/T DEMONSTRATION**
  - Design of subMW unit initiated

Technology

Direct FuelCell®

High Temperature Internal Reforming Direct FuelCell®

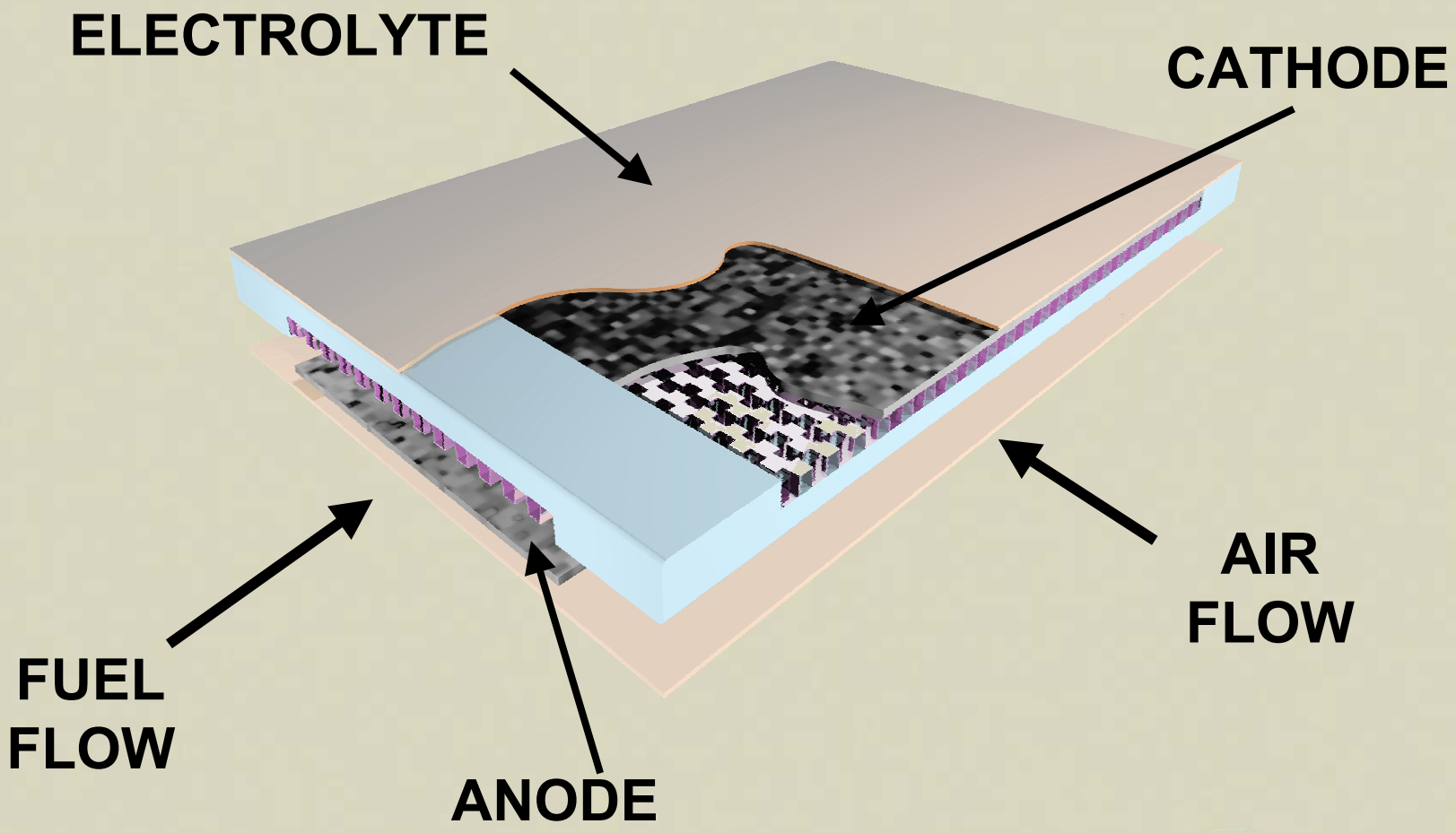


The Direct FuelCell® Advantage

- **Optimal Operating Temperature**
  - Uses commonly available materials
  - No noble metal catalyst
  - High temperature by-product heat
- **Internal Reforming**
  - H_2 generated internally
  - High efficiency
  - Simpler system
  - Negligible No_x
  - Reduced cooling requirement
- **Atmospheric Pressure Operation**
  - Allows unattended operation
  - More reliable

DFC Components

Fuel Cell Construction



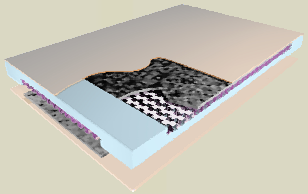
FuelCell Energy Products

Sub-MW Power Plant

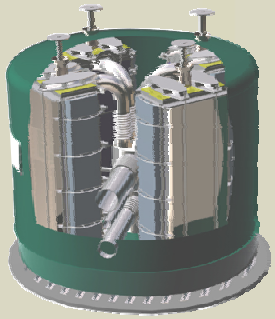
- Building block approach provides scalability and a standardized product to manufacture

Sub-MW Module

Stack



Fuel Cell



MW Module

MW Power Plant

DFC Stacks Ready For Module Integration

FuelCell Energy Core Products – 250kW-10MW

DFC® 300

DFC® 1500

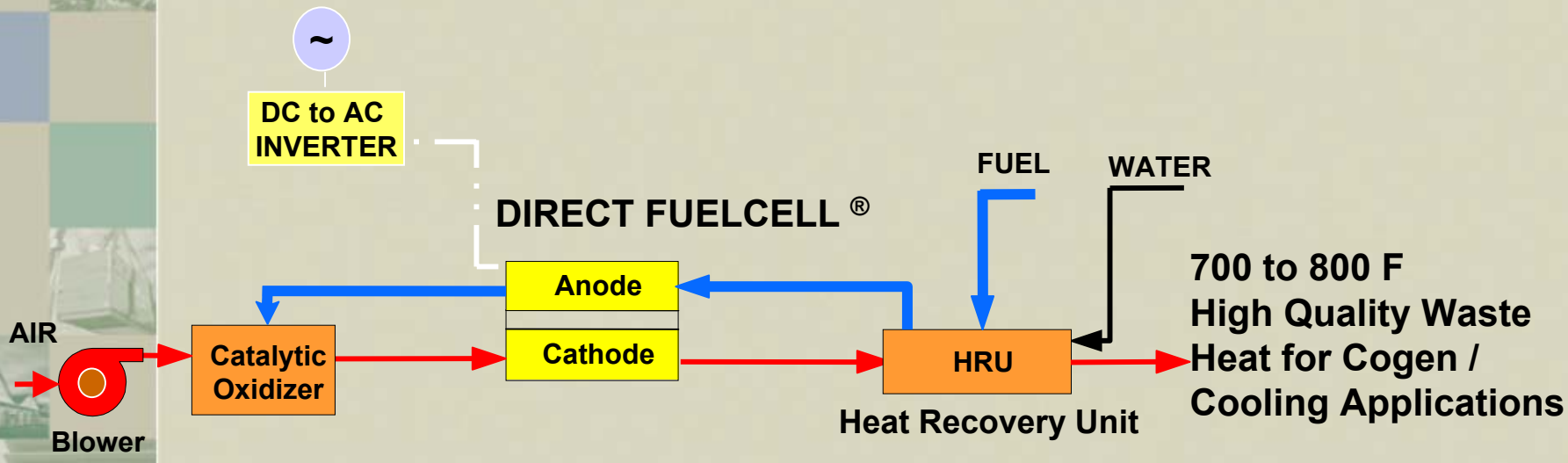
DFC® 3000

Product Characteristics

- High temperature, carbonate fuel cell power plants for base load commercial and industrial applications
- High electrical efficiency
- High value waste heat by-product for cogeneration
- Internally generated hydrogen from readily available fuels such as natural gas – operating at customer sites today

Multi-MW Grid Support

Simplified System Diagram
Baseline Simple-Cycle Powerplant



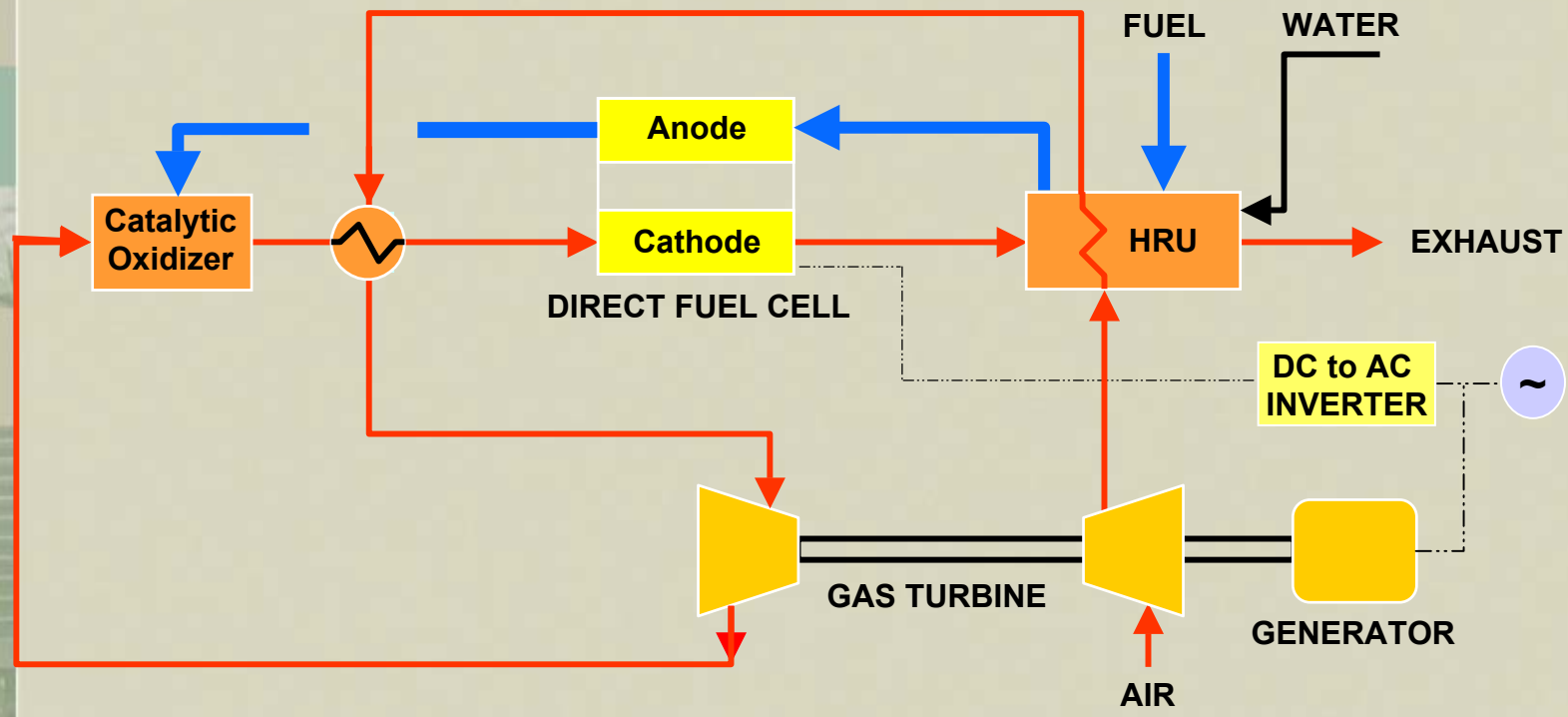
Residual 20 - 25% Fuel in Anode Exhaust is Used in Catalytic Oxidizer to Preheat Cathode Air

Cathode Exit Gas is used for Fuel Preheat and Water Vaporization

No External Reformer

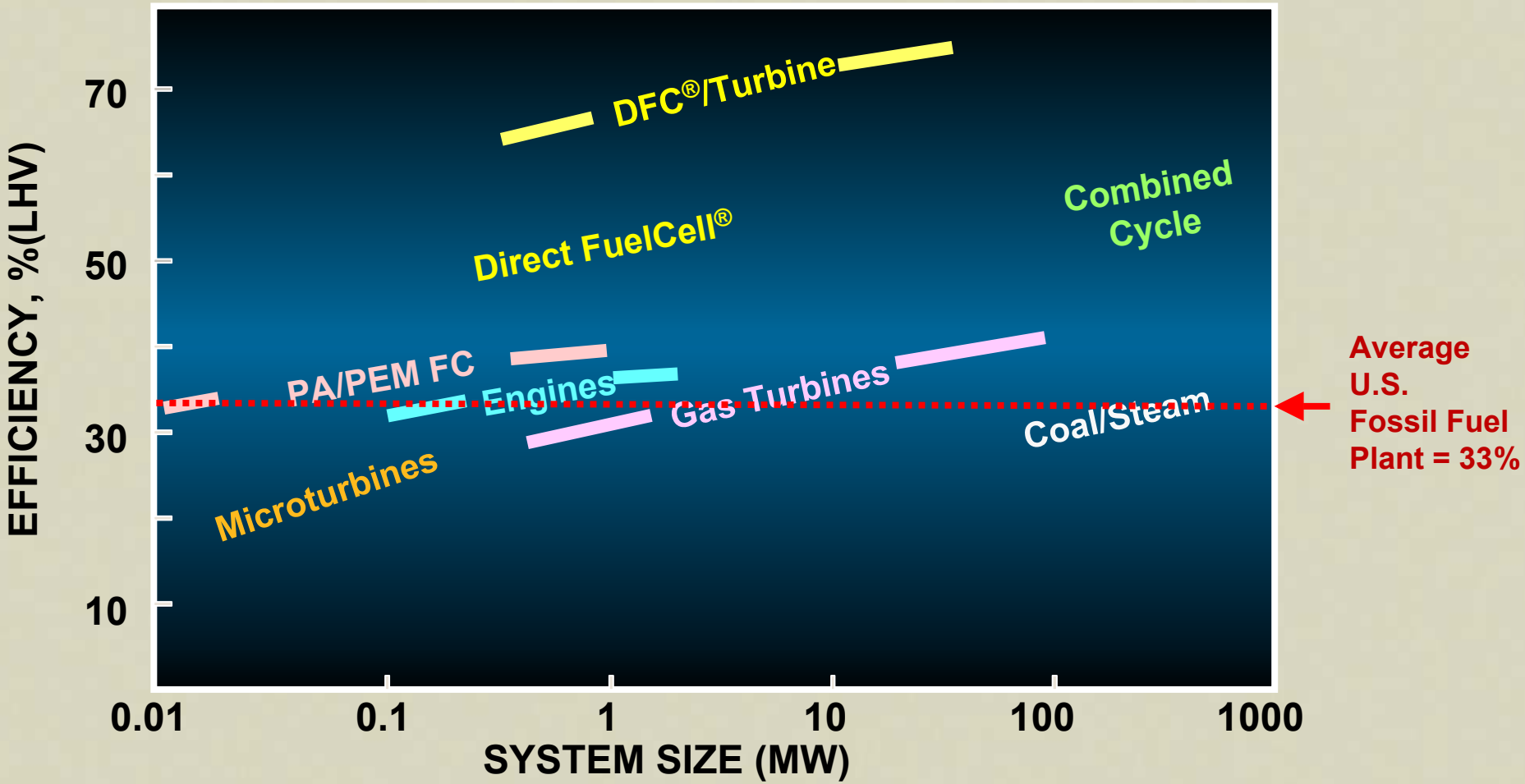
Air Blower Only Prime Mover

High Efficiency Hybrid DFC® / Turbine Power Plant



- *Low Cost of Electricity Compared to Combined Cycles*
- *Efficiencies of ~ 75% are Possible*

Fuel Cells Conserve Energy Resources



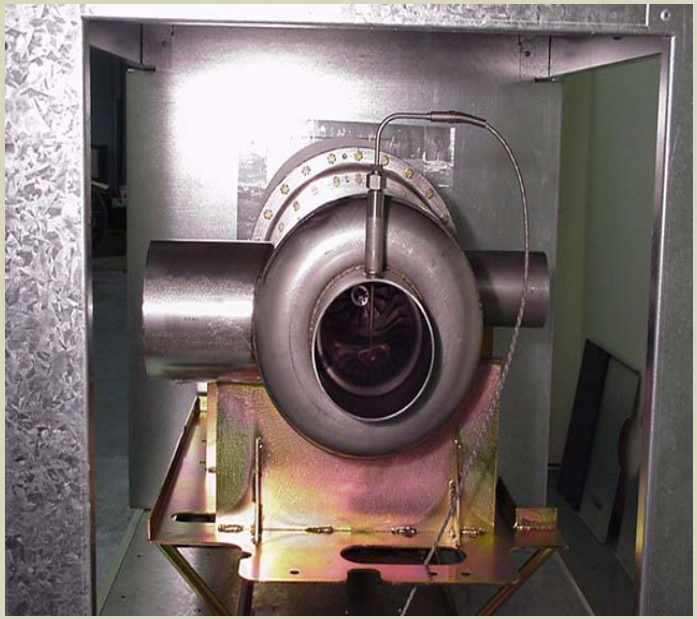
Subscale DFC/T Integration Test Objectives

- Proof-of-concept DFC/T system – integration of 250 kW DFC® stack with microturbine
- Gain operational and design experience
- Develop and identify the design of critical components for DFC/T systems

SubMW DFC/T System: Microturbine Characteristics

- Optimized turbine inlet temperature at ~1400-1500º F
- Mechanical modifications (compressor exit port and turbine inlet port)
- Range of air flows suitable for fuel cell operation (1-1.6 lbs/sec)
- Capability to control air flows with load
- Integration of microturbine's controller/data acquisition hardware to fuel cell control system.

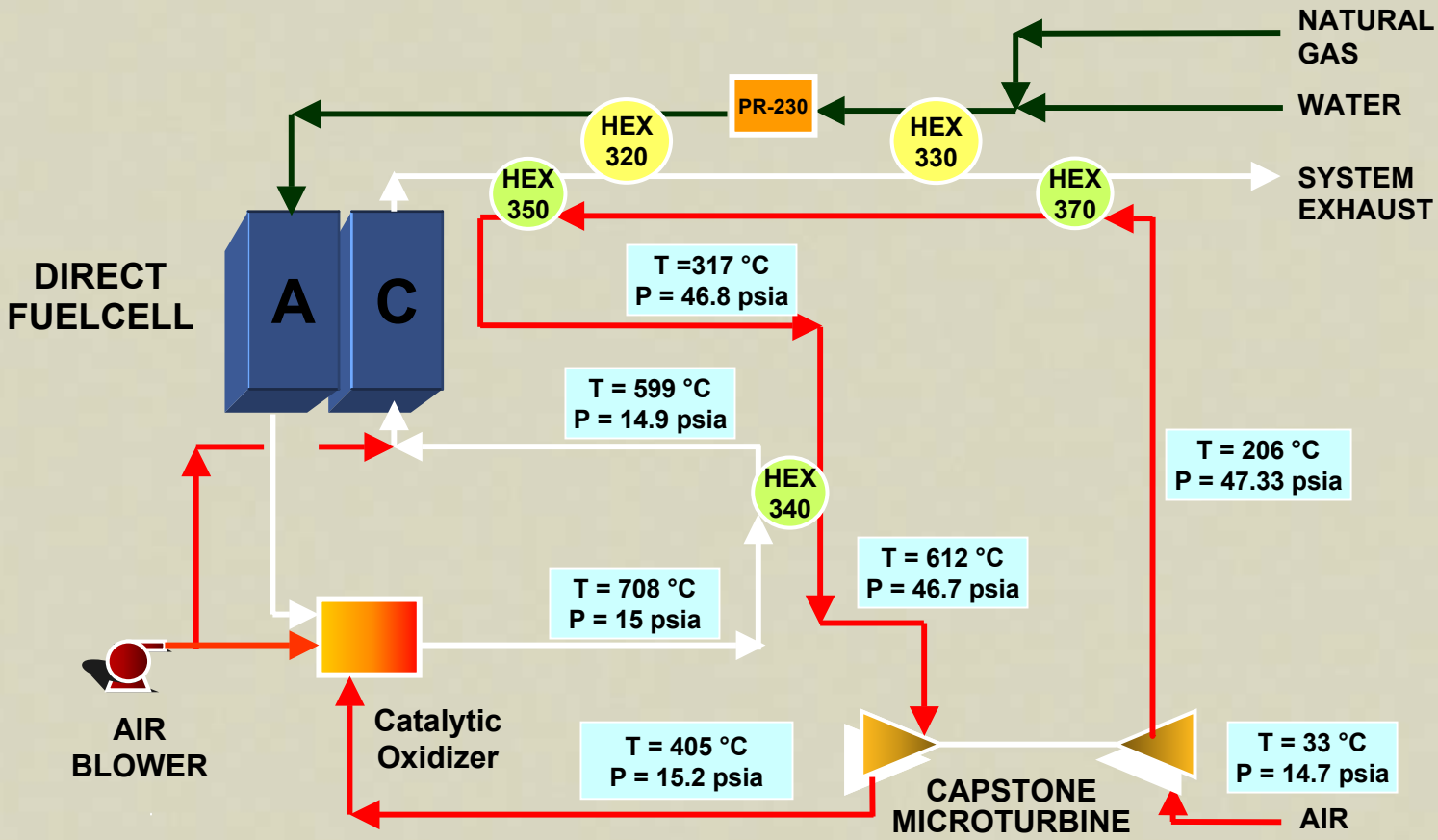
Modified Capstone Model 330 MicroTurbine™



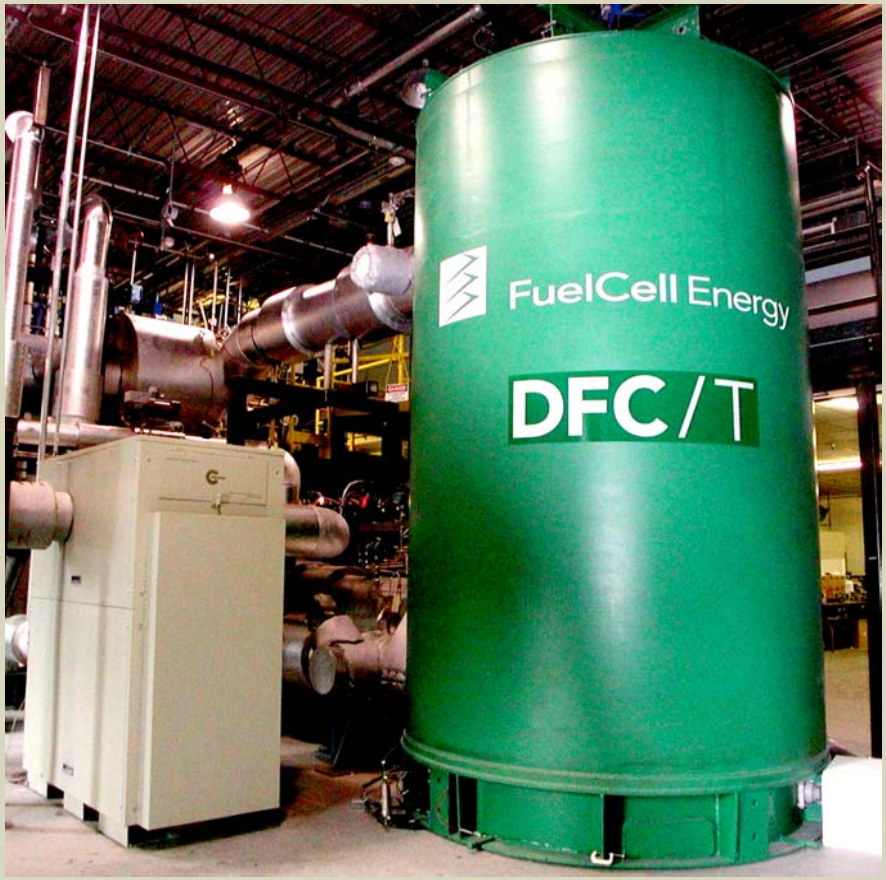
Capstone Simple Cycle Model 330 MicroTurbine™ at FCE Test Area

SubMW Scale DFC/T Power Plant Process Flow Diagram

- ***Flexibility of operation to run the fuel cell either as standalone unit or integrated with the microturbine is incorporated***



Testing Of Alpha Unit With Micro Turbine



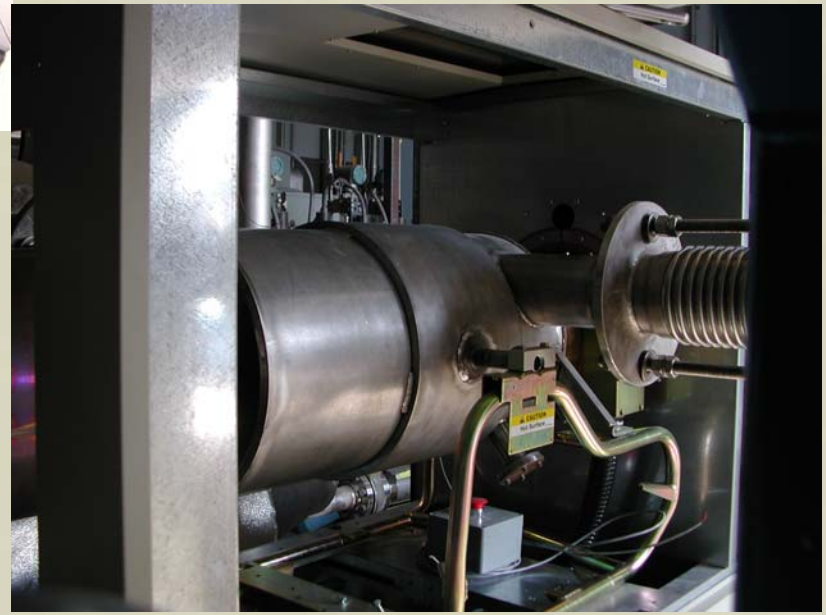
- ***Successful proof-of-concept testing of 250kW Direct FuelCell® with Capstone Micro turbine verifies design concepts.***

Subscale DFC/T Proof-of-Concept Test Results

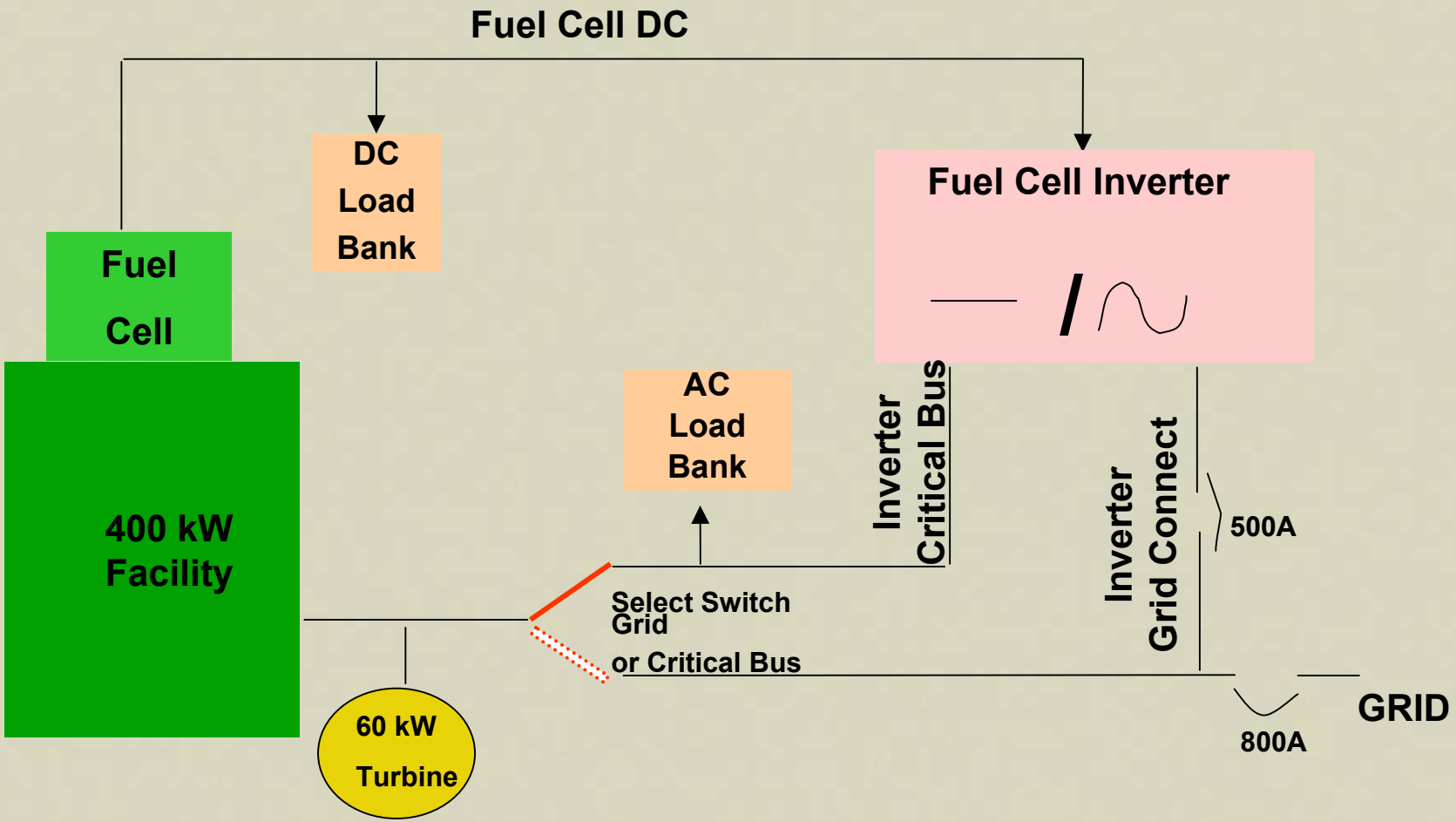
The stack was operated for over 6,800 hours, including 2,900 hours of turbine (DFC/T hybrid) operation.

Fuel Cell DC Power	222.8 kW
Gross Fuel Cell AC Power (est.)	206.3 kW
Microturbine Power	9.5 kW
Parasitic Power	6.5 kW
Net AC Power (est.)	209.3 kW
Net Efficiency (LHV)	50.7%
Net Efficiency Adjusted for ISO Conditions (LHV)	51.7%

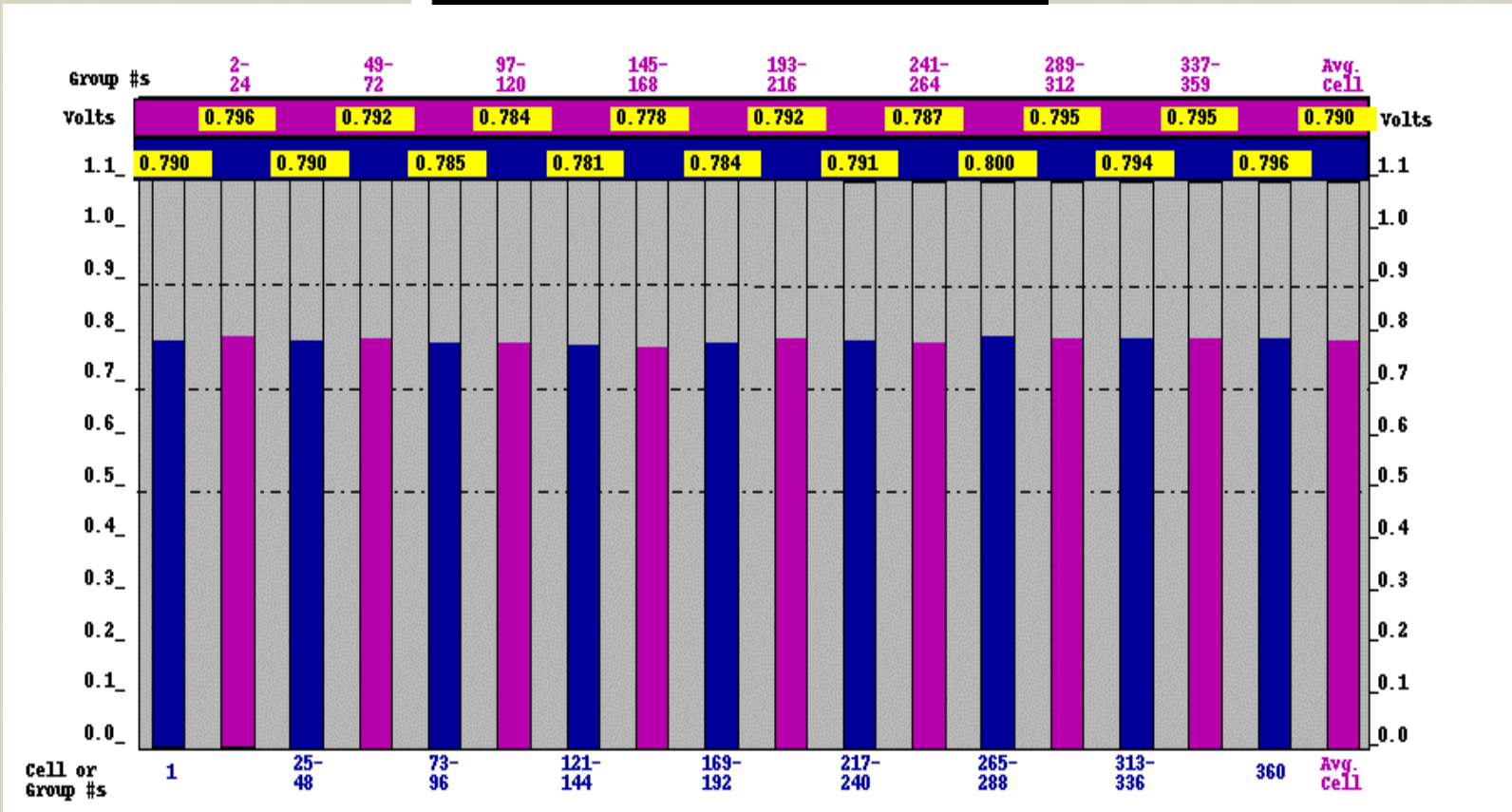
Capstone C60 Microturbine Integrated with Balance of Plant



SubMW DFC/T Electric Diagram



Performance Characteristics of 250kW Alpha Unit



STACK FA-100-3 PERFORMANCE UNIFORM CELL PERFORMANCE

Recent Accomplishments

- The microturbine was utilized as the only source for supplying fresh air to the system
- The tests of the power plant heat-up confirmed the stable and well-controlled with a the microturbine
- The subMW DFC/T system benchmarked the operation at ~ 250 kW in grid connected mode with a dc-to-ac inverter and the microturbine connected to the grid in parallel.

Objectives Met

- Verified DFC/T® concept
- Modes of operation tested
  - Fuel cell only
  - Fuel cell with turbine integrated and operated at various operating conditions
- Thermal management confirmed
  - Fuel cell operating temperature
  - MT expander inlet temperature
- Trip/emergency scenarios tested successfully
- Refinement of control strategies thru operational experience

SubMW Class DFC Stationary Product: DFC® 300A

Plant Specifications

Power Output	Efficiency (LHV)	Heat Rate
250 kW	47 %	7,260 Btu/kWh

Emissions

NOx	< 0.3 ppmv
SOx	<0.01 ppmv
CO	<10 ppmv
VOC	<10 ppmv

Available Heat

Exhaust Temperature	~ 650° F
Exhaust Flowrate	3,000 lbs/hr
Exhaust Absolute Humidity	~20% by volume

SubMW Class DFC/T® Demonstration Units

INTEGRATION OF MICROTURBINE IN DFC® 300 FUEL CELL SYSTEM

Future Developments

- Continue sub-scale DFC/T power plant tests with a Capstone model C60 Microturbine
- Complete design of the Multi-MW DFC/T power plant
- Investigate suitable gas turbine and recuperator technologies for DFC/T systems
- Design, fabricate and test a subMW DFC/T unit to be tested at Danbury, CT, followed by field demonstration of a second unit in Montana